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On the moisture content of standing grain and the time available for combining - a preliminary working note

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1. Introduction

If we take as our starting point Farm Mechanisation Study No 18 - The utilisation and performance of combine harvesters, 1969 - then several interesting observations emerge.

Firstly, on many farms the combine harvester is the most expensive single piece of equipment. The extra cost of purchasing a larger model in a given series may be of the order £1000. In assessing the seasonal capacity of a combine (acres harvested per season), the recommended expression for combine characteristics (basically size) involves an assessment of both management performance and likely weather. Weather is written in, in terms of the number of hours available for combining and the average crop yield. From the data available in the study, weather factors are at least as important as any other in determining combine size. If information were made available on the variability of combining time from season to season, then the individual farmer could put a figure both to the cost of the 'insurance' given by a combine larger than the minimum and the extent of the 'risk' then covered.

Secondly, and perhaps more importantly, there can be considerable financial penalties if combine capacity is insufficient. There is evidence that the direct penalty (additional losses by shedding and at the header) for leaving barley standing once a suitable field moisture content has been achieved may be of the order 2 to 3 cwts/acre (over a period of 2 weeks). This additional loss will vary with grain type and variety, but the figures quoted approach 10% of the harvested yield. Delay in field work at this time may also imply penalties for subsequent crops through inadequate stubble cleaning, inadequate autumn ploughing and drilling, or difficult root harvests.

This interest in the time available for combining raises the antecedant questions of

(i) just how grain moisture content responds to weather factors.
(ii) the time (date) at which harvesting will begin (since grain moisture content appears to be the prime determinant for most growers).

Field information to help resolve some of these points is currently being collected by ADAS; it was considered that some preliminary work would be useful, on such earlier data as could located, if only to establish methods of approach.

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2. The response of standing grain moisture content to weather

For the field drying of a cut hay crop, ROY (1969) assumes a rate of moisture loss proportional both to the drying capacity of the environment and the moisture content of the drying crop (at a given point in time).

With drying capacity expressed in terms of potential transpiration, Eo, and a constant of proportionality dependent on the amount (yield) of crop being dried, this leads, during dry spells, to an exponential rate of drying and an expression of the form.

$$\ln(xf) - \ln(x_o) = \Delta \ln = -A \sum E_o \quad - - - - - - - (1)$$

where x_o = initial moisture content (dry weight basis)
x_f = final moisture content
A = a constant of proportionality
$\sum E_o$ = accumulated potential transpiration over the period between which x_o and x_f are determined (mm).

Such an expression shows a good fit with measurements of the change of moisture content with time.

CRAMPIN AND DALTON (1971) analyse some earlier data of ARNOLD (1955) and suggest, for the moisture content of a standing wheat crop an exponential decrease of the difference between actual and equilibrium moisture contents during dry spells (moisture again expressed on a dry weight basis).

For the water loss of drying field crops the assumption of an exponential drying rate would appear to be a sensible first approach.

3. The present model

(i) Moisture loss

We need to establish first the particular growth stages and range of grain moisture contents with which we are dealing.

WHITEHOUSE (1968) reports the earlier work of WHITMORE that by 4 to 5 weeks after anthesis (by some date in the last 10 days of July, at Cambridge) the dry matter content of a barley crop has ceased to increase. The moisture content of the crop at this time may still be of the order 35% wet weight basis (54% dry weight basis).

The equilibrium moisture content curve of cereals such as wheat and barley, when plotted against ambient Relative Humidity (R H) shows a typical sigmoid form. Extrapolating to an ambient RH of around 100%, this paper places an arbitrary value and upper limit of 25% wet weight basis (33% dry weight basis) to the equilibrium moisture content of grain.

For grain of between 54% and 33% moisture content (dry weight basis) we envisage a model in which there is no translocation of internal moisture, in which there is no further photosynthesis and no redistribution of internal moisture between increased amounts of photosynthates, and a situation in which a change in moisture content can occur in one sense only, namely downwards. The presence of free external moisture is taken not to increase the internal

moisture content of the grain, but requires that energy (measured in units of potential transpiration) should be applied preferentially to remove the external moisture before internal drying can proceed.

For grain of less than, and up to and including 33% moisture content (dry weight basis), a change in moisture content may occur in either sense, moisture being taken up during periods of surface wetness, moisture being removed during dry spells, at a rate proportional to some function of energy applied (energy measured in units of potential transpiration). Once having reached a moisture content of 33% dry weight basis, this model does not permit rewetting to take the internal moisture above 33% (dry weight basis).

(ii) Moisture uptake

Work leading up to the present note suggested there was no great difficulty in fitting an expression of the form shown in equation (i) to the drying of standing grain. The major problem is in quantifying the uptake of moisture during and after periods of rain. With meteorological data only available currently on a daily basis ie, daily rainfall totals, daily sunshine hours, then the duration of rainfall, the rate of drying of the surface of the grain after wetting and so the duration of surface wetness are not quantities that can be determined with any precision. Yet daily rainfall, daily sunshine etc form the greater bulk of our past weather statistics and it is quantities such as these, which have eventually to be transformed into probable combining hours to give the season to season distribution that we require.

The work of BRUCK and VAN ELDEREN (1969) on moisture levels and their rates of change has been grafted on to the simulation model for plant growth developed by BROUWER and DE WIT (1968). The time steps considered here were of the order 0.1 hour. The meteorological parameters written in to the study included rainfall amount and duration and these are also the parameters employed by CRAMPIN AND DALTON (1971) in their development of regression equation for moisture uptake, an intermediate step in their estimate of combining hours.

Comments here are that the present time we cannot match the Dutch work, which in any event has not been tested on independent data (the moisture progress curve (for one season only) has been fitted). Secondly, the physics of the work of CRAMPIN AND DALTON (1971) is probably suspect. The ambient environment for moisture loss is, by these authors, specified solely in terms of ambient temperature and humidity. Whilst such an approach may be valid in circumstances where the energy available for vapourisation of grain moisture is not limiting eg in high temperature bed drying, it is not likely to be valid for the field drying of crops, where source of energy is simply solar radiation. Though the expression developed by CRAMPIN and DALTON (1971) shows that grain moisture content approached grain equilibrium moisture content exponentially, this in itself is not sufficient to meet the objection first raised, namely that the drying potential of the environment should include some energy factor explicitly.

Though reported work does not so far solve our problem we can nevertheless extract information that is relevant.

From the work of BRUCK and VAN ELDEREN (1969) we infer that the maximum rainfall intercepted by the ears of a grain crop is likely to be of the order

0.5 mm/unit area. From the work of ROY (1969) we infer that the effects of dew are minimal and can be neglected, in terms of the energy needed to remove it; also that the large and rapid changes of moisture content apparently to be associated with dewfall are, in the main, due to the removal of surface rather than internal moisture.

The present model assumes then that rainfall amounts (p) up to and including 0.5 mm will be intercepted completely by the standing grain, will not lead to internal moisture uptake and after ROY (1969), will require energy (potential transpiration) of (2 p) mm to remove it.

For rainfall amounts greater than 0.5 mm, a quantity 0.5 mm will be held by the grain and will require 1 mm of potential transpiration to remove it.

With rainfall greater than 0.5 mm, prolonged wetting of the grain surface will occur and some uptake of internal moisture will follow.

Taking a typical yield of 35 cwts/acre, this gives on conversion, a yield of 0.43 kg/m^2.

A crop of X% moisture content (dry weight basis) now has water equivalent to .0043 X mm/unit area.

It was assumed that moisture uptake would depend, among other things, on the difference between actual and maximum water content.

For a crop initially at X% moisture content, wetted by rain, a moisture uptake of

$$k\,(33-X)$$

was assumed, with a final moisture content corresponding to

$$(.0043X + k\,(33-X))\text{mm unit/area}$$

4. <u>The definition of combining time</u>

Though some advantages have been mentioned of, in effect, buying time for field hygiene and autumn cultivations, through taking an early and moist cut of grain, and drying artificially, most farmers at the present time will wait until the grain moisture content falls below 20% wet weight basis (25% dry weight basis) before beginning harvest.

This means that in looking at the time to the start of harvest we have to consider both the grain moisture content ranges 54%-33% (dry weight basis) and 33% moisture content and below.

In looking at the time available for combining, we need to identify the time during which the crop will be free of surface wetness and the grain moisture content somewhat less than 33% dry weight basis. Since few farmers will from choice take a cut with grain moisture contents in excess of 22% wet weight basis (28% dry weight basis), we should presumably identify the hours when the surface of the crop is dry and the grain moisture content less than or equal to 28% (dry weight basis).

5. The data

Observations of standing grain moisture content (1 per day, time not specified) had been made at irregular intervals by WHITMORE of the Plant Breeding Institute (PBI), Cambridge over the years 1958-1961. These data were kindly made available to me. They were supplemented by daily rainfall amounts observed at NIAB Cambridge and by daily potential transpiration amounts, obtained essentially from daily radiation totals at MRU Cambridge.

6. Data Manipulation

To follow the day by day changes in standing grain moisture content the procedure now indicated was adopted.

(a) From the daily total of potential transpiration, E_o mm, subtract the amount needed to remove any surface moisture due to rainfall during that day.

Use the resultant value of E_o to calculate a change in moisture content from that at the beginning of the day, employing an expression,

$$\ln (x_f) = \ln (x_o) - A E_o$$

(b) Calculate the water (mm/unit area) associated with the moisture content (x_f).

Calculate the moisture uptake due to any prolonged wetting.

Take the resultant water content of the grain as that appropriate to the moisture content at the end of the day.

7. Some difficulties

Grain moisture contents were reported only at intervals of several days. In the sample of observations available from PBI, only two pairs of moisture content evaluations were made which fell within completely dry spells.

Applying an expression of the form of equation (1) gave in the one instance

$$A = \frac{\Delta \ln}{\sum E_o \text{ mm}} = 0.05$$

and in the other

$$A = \frac{\Delta \ln}{\sum E_o \text{ mm}} = 0.02$$

In fact the change in moisture content implied by a given value of E_o is not particularly sensitive to the value assigned to A. For example

(a) $Eo = 1$ mm ; $\frac{\Delta \ln}{\sum Eo} = 0.051$; $x_o = 20\%$

$\ln x_o = 2.3026 + .6930$

$\Delta \ln =$

$\ln x_f = 2.3026 + .6420 = \ln 19.0$

$x_f = 19.0\%$

(b) $Eo = 1$ mm ; $\frac{\Delta \ln}{\sum Eo} = 0.046$; $X_o = 20\%$

$$\ln x_o = 2.3026 + .6930$$
$$\Delta \ln = .0640$$
$$\ln x_f = 2.3026 + .6470 = \ln 19.1$$
$$x_f = 19.1\%$$

However, values of A equal to 0.05 and 0.02 do not appear reconcilable and a choice between them has to be made. If we take note of varietal differences and give weight to the fact that slower maturing varieties are characterised by a slower rate of moisture loss in the field, then it would seem reasonable to base present and future work on the faster maturing varieties, and on the value 0.05 for A. Such a value would be consistent with the observation that moisture contents may change by something of the order 3% - 6% on a really good drying day.

eg $x_o = 25\%$; $E_o = 4$mm ; $\Delta \ln = 4 \times 0.05 = 0.2000$

$$\ln 25 = 2.3026 + .9163$$
$$\ln \quad = \quad .2000$$
$$\ln x_f = 2.3026 + .7163 = \ln 20.5$$
$$x_f = 20.5\%$$

By taking one of the years (1958) for which data was available, it was possible, by working backwards and forward in time from the days on which grain moisture contents were specified, to place values on (k) the multiplying factor for water uptake. A given value of (k) could then be associated with the characteristics of rainfall total and potential transpiration (or potential transpiration excess) for the day.

The values so assigned to (k) could then be validated, by examining predicted and reported grain moisture contents, when the day by day, step by step procedure was applied to other years.

It soon become apparent that for consistency between observed and predicted values of moisture content, it was not possible to assign unique values of (k) for days characterised by rainfall amount and potential transpiration.

Regression analysis did not seem appropriate since the form of the relationship between (k) and E_o, for example is almost certainly not linear, but probably parabolic, with high values of (k) and moisture uptake associated both with low values of Eo (dull; rain during day light hours) and with high values of E_o (sunny; rain and a long period of wetness at night).

8. A solution

The inability to establish one-to-one relationships between sets of parameters frequently represents an impasse. However, we recall that we are looking, eventually, for long term planning data - for indications of the range, through the years, of the time likely to be available for combining in any one season and for an indication of the probability of a particular number of hours being available in any one season.

This being so, it seemed possible that worthwhile answers could still be obtained, if one accepted that unique values of (k) were not going to be obtained (in terms of daily rainfall totals, daily values of potential transpiration, daily values of sunshine etc) and if one simply derived values of (k) which led to predicted grain moisture contents matching those which were reported . If probabilities were then attached to the values of (k) so obtained, then the required long term planning data could be generated by a simulation study with past weather data, values of (k) on any one day being assigned with the help of a table of random sampling numbers and reported daily values of rainfall amount and duration, potential transpiration, sunshine, etc.

Conclusion

The present note is put forward as a basis for discussion among the people interested in the ADAS Experiment - National Reference Code CL3; Project Title - The relationship between crop maturity and harvested yield of cereals.

Any comments, suggestions, criticisms are welcomed.

It is suggested that detailed work on the final estimates of combining hours etc should await the analysis of the field data being collected by ADAS during the 1971 harvest.

In the mean time however, work on the contingency tables between rainfall amount and duration, between potential transpiration, radiation and sunshine, etc could go forward.

Table 1 shows the relationship found for the PBI data between the values of (k) (the multiplying factor for moisture uptake) and daily rainfall and potantial transpiration.

Table 2 shows a suggested frequency distribution to be associated with a random sampling table (00-99).

Meteorological Office
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Table 1

Contingency table for (k), the multiplying factor for moisture uptake

	Eo<1	1.5>Eo≥1	2.0>Eo>1.5	2.5>Eo≥2.0	3.0>Eo≥2.5	3.5>Eo≥3.0	4.0>Eo≥3.5	Eo ≥4.0
p=.51-1.0mm			.0035		.004 .0043			
p=1.1-2.0		.00045		.0004				
p=2.1-3.0		.00045	.0004		.0004 .0004		.002	
p=3.1-4.0		.0002		.0001				
p=4.1-5.0				.002 .004	.003		.002	.002
p=5.1-6.0		.004	.002	.0028 .0029 .003 .003 .006	.003			
p=6.1-7.0				.003 .0043	.003			
p=7.1-8.0							.002	
p=8.1-9.0		.004	.002					
p=9.1-10.0		.003						
p = 10.1	.0002 .002							

Table 2

Values of (k) to be associated with numbers drawn from a random sampling table (00-99)

$p \leq 4.0$ mm

Random number	(k)
00-07	.0001
08-15	.0002
16-49	.0004
50-66	.00045
67-74	.002
75-82	.003
83-39	.004

$p \geq 4.1$ mm

E_o values available

$E_o < 2.5$ mm

Random number	(k)
00-27	.002
28-71	.003
72-99	.004

$Eo \geq 2.5$ mm

Random number	(k)
00-49	.002
50-99	.003

$p \geq 4.1$ mm

E_o values not available

Random number	(k)
00-34	.002
35-79	.003
80-99	.004